Volume 31 September, 1945 *Number 9*

Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

INDUSTRIAL GEARS

Designing for Lubrication

PUBLISHED BY

THE TEXAS COMPANY

TEXACO PETROLEUM PRODUCTS

SCHEDULE OF TEXACO LUBRICANTS FOR INDUSTRIAL GEARS

TYPE OF GEAR	DESCRIPTION	AMBIENT TEMPERATURES	NORMAL OPERATION	HEAVY DUTY, WHERE EXTREME PRESSURE LUBRICATION REQUIRED	IN PRESENCE OF WATER OR CHEMICALS
SPUR, BEVEL, SPIRAL BEVEL, ANNULAR OR INTERNAL	Gears enclosed, casings oil tight, bearings separately lubricated.	Below 40° F.	Thuban 80	Meropa Lubricant–1	
		40° to 100° F.	Thuban 90	Meropa Lubricant–3	
		Above 100° F.	Thuban 140	Meropa Lubricant–6	
	Gears enclosed, casings oil tight, gear lubricant to serve bearings as well.	Below 40° F.	Algol Oil Altair Oil	Meropa Lubricant–1	
		40° to 100° F.	Ursa or Aries Thuban 90	Meropa Lubricant–1 or 2	
		Above 100° F.	Ursa Oil Heavy Auriga or Thuban 90	Meropa Lubricant–3	
	Gears entirely exposed, hand lubricated.	Below 40° F.	Crater No. 1	Meropa Lubricant–2 or 3	Crater A
		40° to 100° F.	Crater Nos. 1 or 2	Meropa Lubricant–3 or 4	Crater Nos. 1x or 2x
		Above 100° F.	Crater No. 3	Meropa Lubricant–6	Crater No. 3x
	Gears exposed, bath lubricated.	Below 40° F.	Thuban 90	Meropa Lubricant–3	
		40° to 100° F.	Thuban 140 or 250 Crater Nos. 00 or 0	Meropa Lubricant–6 or 7	Crater A
		Above 100° F.	Thuban 250 Crater Nos. 0, 1, or 2	Meropa Lubricant–7	Crater No. 1x
HELICAL OR HERRINGBONE	Gears enclosed, casings oil tight, bearings separately lubricated.	Below 40° F.	Thuban 90	Meropa Lubricant–3	
		40° to 100° F.	Ursa or Aries Thuban 90 or 140	Meropa Lubricant–3 or 6	
		Above 100° F.	Thuban 140	Meropa Lubricant–6	
	Gears enclosed, casings oil tight, gear lubricant to serve bearings as well.	Below 40° F.	Algol or Altair	Meropa Lubricant–1	
		40° to 100° F.	Ursa or Aries	Meropa Lubricant–1 or 2	
		Above 100° F.	Ursa Oil Heavy, Auriga or Thuban 90	Meropa Lubricant–6	
	Gears entirely exposed, hand lubricated.	Below 40° F.	Crater Nos. 0 or 1	Meropa Lubricant–6	Crater No. 1x
		40° to 100° F.	Crater Nos. 1 or 2	Meropa Lubricant–7 or 8	Crater Nos. 1x or 2x
		Above 100° F.	Crater Nos. 1 or 2	Meropa Lubricant–7	Crater Nos. 1x or 2x
	Gears exposed, bath lubricated.	Below 40° F.	Thuban 90	Meropa Lubricant–3	Crater A
		40° to 100° F.	Thuban 140 or 250 Crater Nos. 00 or 0	Meropa Lubricant–6 or 7	
		Above 100° F.	Thuban 250 Crater Nos. 00 or 0	Meropa Lubricant–7	

(Continued on Inside Back Cover)

LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

Published by

The Texas Company, 135 East 42nd Street, New York 17, N. Y.

Vol. XXXI | September, 1945 | No. 9

Change of Address: In reporting change of address kindly give both old and new addresses.

INDUSTRIAL GEARS

Designing for Lubrication

NEW MACHINERY must be designed with an eye to the way it is to be lubricated. Lubricants are no more universally adaptable than other machinery materials. How successfully any gear lubricant will function over a fair range of the expected operating conditions depends, therefore, upon how carefully the designer studied these conditions when he planned the installation.

The original design of any machine involving speed change or power transmission gearing includes certain conditions which are fixed as far as the operator is concerned. For example, the type of gear tooth, the size, the speed reduction ratio, the housing and the manner of lubrication.

> **GEARS are of interest to everyone.** Whether we know it or not we travel by virtue of the speed reduction and power transmitting ability of gears. Without gears, production of food, fuel, clothing and all of our other daily comforts might still be but an ideal. Gears enabled the engineer to transform the speed of the steam turbine, internal combustion engine or electric motor down to that speed at which it is most economical to run the machine being driven. Gears enable individual parts on the same machine to be run at different speeds — some high, some low.

There are other conditions, some of which may be more variable. Table I indicates these in the form of questions which must be answered when selecting a gear lubricant. The answers "yes" or "no" in the Table apply to some of the most common designs; "no" in any case, suggests a possible difficulty which requires due consideration.

Exposed gearing is usually confined to heavy duty, slow moving machinery; here spur gears are commonly used. On such installations, tooth loading is purposely kept low by the designers; as the operating clearances are fairly large, satisfactory lubrication can be maintained by coating the teeth periodically with a heavy bodied, adhesive gear lubricant. Exposed gears are practically always lubricated independently of their shaft bearings, so here there is no worry about choosing a lubricant which is also suited to the bearings.

Greater refinement in design is necessary, however, when the operating speeds are increased. Then for straight line transmission the designer usually favors the helical or herringbone type. As such mechanisms are suitably housed the designer can provide for bath lubrication, or plan for a pressure oil circulating system. Either permits the use of a more fluid type of gear lubricant according to the temperature. Oils of around 500 seconds Saybolt Universal Viscosity at 100° Fahr., for example, are applicable on the precision cut herringbone gears of the marine steam turbine type.

Precision Service

Where precision gearing is involved, both the lubricant and the gears must be protected by means of a properly designed gear case which is as nearly oil tight as possible. In many installations, leakage of gear oil can be particularly harmful to adjacent mechanisms on the machine. A case in point of par-

ticular interest would be leakage of gear oil from the differential gears in an automotive vehicle; here oil leakage might get on to the brakes to render them inoperative.

In designing a gear lubricating system it is important to consider the physical properties of the lubricants which would be customarily used in the particular installation.

For example, if a heavy oil is employed during warm weather or continued operation in order to avoid leakage, and the temperature drops appreciably, such an oil may solidify to the point that channeling or even a complete freeze-up may occur.

be failure of the tooth surfaces. Tooth breakage is rarely attributable to lubrication. Metal structure, faulty design, abuse or excessive overloading are more usually the cause. Lubricants which would otherwise be amply protective cannot insure against failure under such conditions, nor can they always keep the temperatures sufficiently below the danger point. Abnormal temperatures from any source whatsoever, can cause imperfect surface lubrication and excessive friction. Then scoring and or scuffing may develop, along with perhaps softening and cracking. Under such conditions the temperature over the contact areas of the teeth has probably

TABLE I
SOME TYPICAL GEAR INSTALLATIONS, SHOWING HOW THE VARIOUS OPERATING AND CONSTRUCTIONAL CONDITIONS CAN BE EVALUATED AS A GUIDE TO DEVELOPING PROPER PROTECTION BY LUBRICATION

Operating Conditions	Bull Gear on Punch Press	Traversing Gear on Excavator	Electric Motor Reduction Gear	Automobile Differential	Domestic Washing Machine Gears
Do Large Operating Clearances Prevail	Yes	Yes	No	No	No
Can Gears be Easily Inspected.......	Yes	Yes	No	No	No
Is Trained Personnel Available for Service	Yes	Yes	Yes	Yes	Yes
Are Periodical (seasonal) Lubricant Changes Made	No	No	No	Yes	No
Are Operating Speeds Low.........	Yes	Yes	May vary	No	No
Are Speeds Relatively Constant......	Yes	Yes	May vary	No	Yes
Does Practically Constant Normal Load Prevail..................	No	Yes	May vary	No	Yes
Are Operating Temperatures Relatively Constant.................	Yes	No	May vary	No	No
Do Gear Lubricants Service Both the Gears and Bearings............	No	No	Yes	Yes	Yes
Is Moderate Lubricant Leakage Permissible	Yes	Yes	No	No	No
Is Drag Due to Lubricant Film a Factor	No	No	Yes	Yes	Yes
Is Lubricant Protected from Contamination	No	No	Yes	Yes	Yes
Will Absence or Unsuitability of Lubrication Make Itself Evident Before Serious Damage Occurs..........	Yes	Yes	No	No	No
Total Unfavorable Conditions.......	5	5	5	8	7

Fortunately, it is customary and practicable to avoid this effect by changing the type of lubricant in accordance with the seasonal temperature change, as it is not always possible to obtain one lubricant which will be entirely satisfactory under both conditions.

WHY AND HOW GEARS FAIL

When a gear tooth fails it may involve actual breakage of one or more of the teeth, or there may become high enough to reduce the viscosity of the oil film to such an extent that the lubricating value of the film on the teeth is negligible. If this continues, more friction, more heat, less lubrication and more tooth failures will result.

On exposed gears, the lubricant must be adhesive as well as viscous—otherwise the film cannot resist the action of centrifugal force.

Where dealing with bath or dip lubricated gears,

choose the lubricant so that at the operating temperature the viscosity will be sufficient to train with the teeth. If the oil is too light an insufficient amount may be carried by the dipping gear to the companion gear or worm. In this case the cooling ability of the lubricant will be lost. Under such conditions, a worm gear for example, may run so hot as to cause the threads to soften and crack, or to result in wiping of the bronze teeth of the worm wheel. For this reason the designers improve the adhesiveness of a worm gear oil by using a compounded product. Other authorities feel that a lubricant containing lead soap (which has mild

Fig. 1–NORMAL WEAR

This condition refers to the gradual smoothing and polishing of the working surfaces resulting from the sliding and rolling action of the teeth. It is frequently spoken of as "running in". With proper design, manufacture and operation, a condition is reached after which wear practically ceases.

E.P. properties) and which is non-corrosive to copper, bronze or steel, provides an added factor of safety. In a worm gear the sliding velocity is greater than in a spur, bevel or helical gear.

Surface Failure – Wear

When the tooth surface of a gear becomes impaired, it may progress through several accepted stages. First, more or less abrasion or rubbing off of the metallic surfaces occurs. This is a form of wear induced by rolling and sliding velocity. Spur, helical or bevel gears being subject to such velocity will often become smooth and highly polished during the initial stages of abrasive wear. To some extent this could be regarded as a "wearing-in" procedure. It is regarded as being related to the viscosity of the gear oil, as it is apt to occur more rapidly with lower viscosity lubricants. A heavier oil or one with E.P. characteristics will present a more durable film on the teeth and retard this type of wear. High tooth loads and low speeds also contribute if the viscosity of the oil is not chosen accordingly. Evidence of wear is most pronounced below the pitch line of the pinion if lubrication has been ineffectual. While abrasive wear is progressing the theory is that the fine metallic particles which are worn off the teeth, mix intimately with the oil film to develop a grinding action.

Scoring and Galling

These normally follow abrasive wear due to actual metal-to-metal contact. Here wear is more severe and tearing of the tooth surfaces is evidenced. Normally this occurs in the direction of sliding. Scoring develops regardless of the hardness of the tooth surfaces, but it often may show more of a tearing nature and develop into galling with softer surfaces where total absence of any oil film has permitted welding to occur between the high spots of the tooth surfaces.

The E.P. Theory

The theory back of this welding action, which, incidentally, led to the development of Extreme Pressure Gear Oils, is of interest. Research has indicated that so long as the opposed teeth are at all times separated by several molecular layers of oil there can be no wear of the type known as abrasion or scoring. If the mechanical attack at the contact areas of metals rubbing together becomes severe enough to remove the ultimate protecting film,

Fig. 2–INITIAL PITTING

This term applies to the formation of small *pits* in the tooth surfaces, as large as the head of a pin or smaller, usually starting in the vicinity of the pitch line, and frequently occurring during the initial period of gear operation. *Pitting* should not be considered as detrimental, unless it advances beyond the *initial* stage. If *pits* occur gradually, and do not increase rapidly, they indicate a temporary condition and may disappear entirely in the course of normal wear.

the clean metals will seize, causing irreparable damage to the surfaces. This seizure, in fact, involves incipient welding, resulting in the gross removal of metal, i.e., tearing. In other words, the volume or thickness of the oil film under the pre-

vailing pressure and sliding velocity determines whether or not an E.P. lubricant is necessary. When boundary lubrication conditions are involved the use of an E.P. oil should be seriously considered. Beyond boundary lubrication it is absolutely necessary. The "Action of Extreme Pressure Lubricants" was discussed in LUBRICATION for August, 1944.

One of the most difficult problems of lubrication which has developed in recent years is in connection with hypoid gears. Intensity of load and speed of rubbing are such that a special lubricant is required. Wherever high power losses and wear prevail there is a problem. Polish wear is desirable,

Fig. 3—PROGRESSIVE PITTING

This type of failure is indicated when the formation of *pits* continues at an increasing rate, both as to number and size. A point may be reached when the unpitted areas of the tooth surfaces are insufficient to carry the load, and complete destruction of the tooth shape may occur, especially after continued operation at relatively high load, and over loading.

but abrasive wear should be avoided. Under high loading the oil film between the high spots becomes extremely thin. So long as it exists at all there can be no clean metal contact, and therefore no abrasion, but this condition can only continue so long as the rate of removal of the film does not exceed its rate of renewal.

Industrial gearing need not be of the hypoid type to require an E.P. lubricant; Loading is a factor. In industry, where gearing is adequately proportioned in line with A.G.M.A. practice, and housed, comparatively fluid lubricants are generally applicable. They are applied to the gear teeth and bearings either by force feed lubrication or splash in contrast to automotive service where bath lubrication prevails (See "Automotive Gears"—LUBRICATION for June 1944.)

Pitting

Pitting is related to surface cracking; it is a fatigue failure. It involves actual removal of surface material to a depth dependent upon the localization of stress. Generally speaking, pitting occurs at low speeds and at low operating temperatures where high torque prevails. Stewart Way* states that:—

"A pit does not result from the gradual enlargement of a small cavity, but results from the growth of a crack which eventually separates a particle from the main body of material. Fatigue cracks can begin without oil, but penetration of oil into the cracks is necessary for their growth to pits. Drilling a very small hole to relieve the pressure of the trapped oil in the crack has been found to stop the growth of the crack. The action by which the high oil pressure is developed at the end of a pitting crack, tending to drive the crack deeper, indicates that the loaded area approaches a crack filled with oil and, by pressure on the surface of the protruding lip of metal above the crack, seals the entrance shut, trapping the oil. Further motion of the loaded area over the crack builds up a tremendous oil pressure inside the crack.

"In general, wear and pitting can be prevented by using oil of sufficiently high viscosity. The effect of increase in viscosity (or increase in running speed) is not so much to prevent penetration of oil into the cracks, as to produce a cushion of oil which will carry a larger fraction of the transmitted load. The remaining fraction would be carried by direct contact of the higher regions of the surfaces. It seems to be this latter system of concentrations of loading that is responsible for the formation of the surface fatigue cracks."

*Paper on "Pitting Due to Rolling Contact." Presented before the Amer. Soc. of Mech. Eng. at the annual meeting in N. Y., Dec. 3-7, 1934. Published in the A.S.M.E. Transactions, Vol. 57, 1935.
*And later findings.

Fig. 4—ABRASION

This condition may be described as a general wearing away of the tooth surface at a comparatively rapid rate. It generally results from the presence of foreign matter such as dirt, grit, or metallic particles in the lubricant. It may also be caused by a breaking down of the material on the tooth surfaces, as for instance in cast iron gears. *Abrasion* appears as fine scratch marks up and down the tooth profiles closely distributed over the surfaces. Lack of proper lubrication may result in *abrasion.*

Dr. Way's general conclusions as a result of his research are of decided interest to those who are concerned with gear lubrication. He makes the following statements regarding the theory of oil penetration as a cause of crack growth, the influence of viscosity and the effect of surface finish:

- "The theory requires that oil be present for pitting.
- There is a diminution of cushioning action using low viscosity oil, and an increased tendency toward a hydrodynamic film when using higher viscosity oils. High viscosity tends to prevent initial formation of cracks, rather than oil penetration and crack growth.
- Cracks will grow only if they have a certain initial direction. This direction is the same as that of pitting cracks observed at a very early stage.
- A rough surface serves mainly to cause concentrations of contact pressure, and stress systems favorable to surface fatigue crack formation, rather than being an indication of the possible presence of initial surface cracks.

"Possible means whereby the load necessary to cause pitting may be increased are as follows:

a–Using no oil

b–Using highly polished surfaces

c–Increasing the viscosity of the oil

Fig. 5–SCORING

This condition results from excessive loading or inadequate lubrication. *Scoring* may occur even in gears which have been properly designed, manufactured and installed, when conditions of operation are such as to cause metal-to-metal contact. The tooth surfaces may be roughened only on small areas and on the same position on all teeth. This may be followed by a general disintegration of the surfaces, if abnormal conditions of operation are continued. *Scoring* in its initial stages may sometimes be eliminated by applying more effective lubrication, such as the substitution of a general purpose E.P. lubricant.

d–Using a very hard surface and tough interior as are obtained by nitriding.

"The first method is obviously not practical and the second is quite expensive. The third method in many cases can be successfully applied. The fourth method deserves much further study."

The Problem Often Solves Itself

Fortunately, actual failure of gear teeth seldom occurs. Wear, scoring, incipient pitting and other conditions – (See Figs. 1 to 13) may develop, as already stated, but they usually can be arrested by proper preventive measures with the result that the gear assembly in question will run successfully for years thereafter. Some authorities feel that at least minor wear is essential to the running-in process whereby local high spots on the tooth surfaces are worn down. While this is going on, localized stresses may be developed which will generally cause some pitting, entirely unrelated to the lubricant used. Partial proof of the assumption that this pitting often corrects itself has been evidenced where the pitting has been cleared up by continued abrasion until relatively smooth and satisfactory mating surfaces have developed on the teeth. Some tooth surface deformations may still be evident, but normally a satisfactory polish is acquired which is indicative of even distribution of the load and satisfactory lubrication.

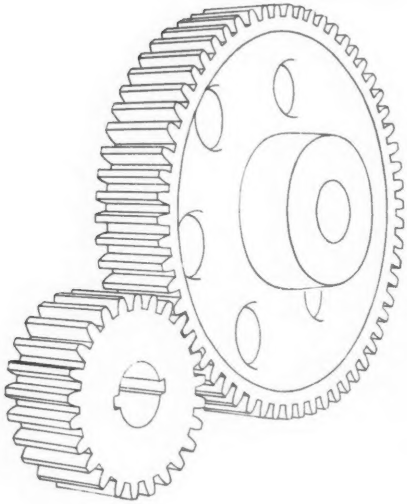
Fig. 6–GALLING

***Galling* is an aggravated condition of scoring caused by particles of metal torn out from the tooth surfaces in a manner that is sometimes referred to as *seizing* and *welding*. This condition is more likely to occur when two comparatively soft gears of the same hardness are operated together under heavy load conditions.**

E.P. LUBRICANTS IN INDUSTRY

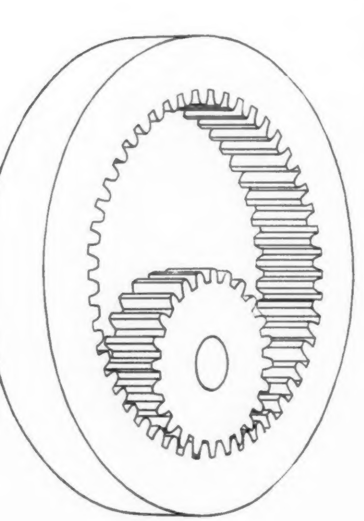
The advantage of the E.P. type of oil for industrial gears has been definitely proved. Iron, steel, paper and rubber are but some of the leading industries which have benefitted. In brief, there is a definite field for the E.P. oil of the right viscosity. Table II is of interest in this regard.

TYPES O G



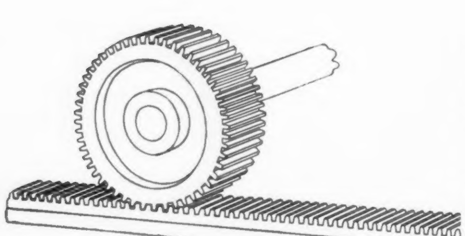
THE SPUR GEAR

A spur gear is a cylinder, wheel, or disk on the surface of which are cut parallel teeth each in a common plane with the axis. Spur gears are most commonly found on industrial machines, working under ordinary conditions, at moderate speeds and with medium pressures exerted upon the teeth.



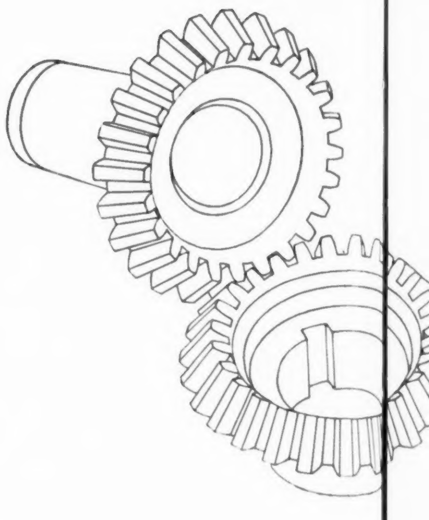
ANNULAR OR INTERNAL GEARING

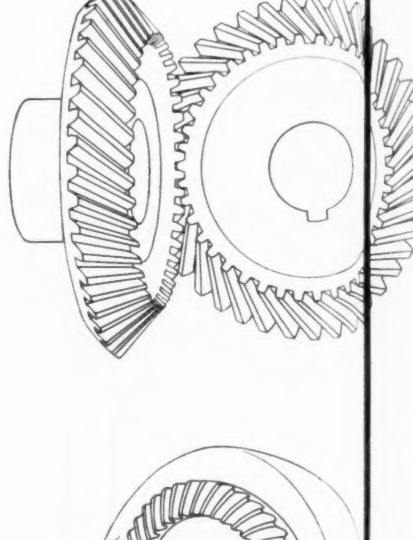
An annular gear is internal in nature; it has parallel teeth similar to the spur gear, but cut on the inside rim or inner surface of a cylinder or ring. The companion pinion of an annular gear, however, must be a standard gear. Internal gear sets are often used for large speed reductions where the direction of motion may have to be reversed. The main driving element on certain types of tractors is a typical example of the use of gears of this type.

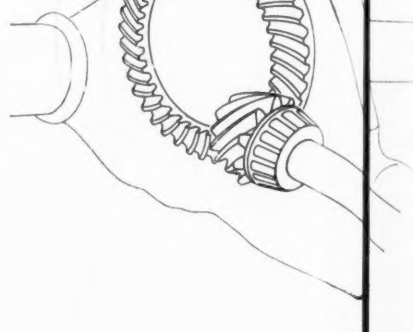


THE RACK AND PINION

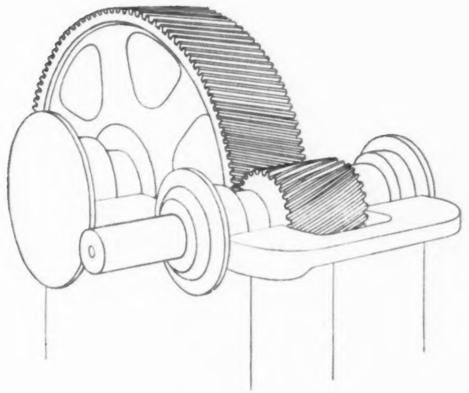
The principle of gearing is also applied to the rack and pinion. The function of this device is to bring about reciprocating motion. The teeth on the rack or straight element are normally of the spur type. A worm or spur gear pinion meshes with the rack.







O GEARS



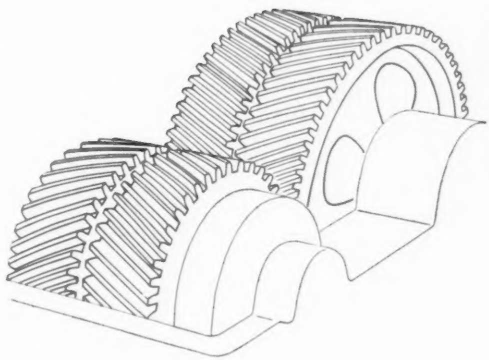
THE BEVEL AND SPIRAL BEVEL GEAR

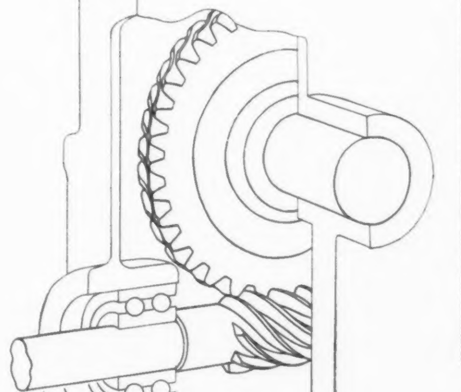
In a bevel gear the teeth are cut on an angular surface, such as would be represented by a truncated cone. They are used for the transmission of motion between shafts with intersecting center lines to form an angle between each other. This is usually a full 90 degree angle with the shafts located at direct right angles with respect to one another. The spiral-bevel gear is also applicable to non-parallel shafting, when it is termed an angle drive; in appearance it approaches the spiral type of tooth.

THE HELICAL AND HERRINGBONE GEAR

The helical gear resembles the spur gear in that the teeth are cut on a cylindrical body, but the helical gear differs from the spur gear in that the teeth are spiraled around the body, rather than formed parallel to the axis of the gear body. Spiraling the teeth provides smoothness of operation.

The herringbone gear resembles two helical gears having reversed directions of spiral, placed side by side, so that the teeth come together to form a chevron pattern. In general, helical or herringbone gears are used with parallel shafts. In the herringbone design, spiraling the teeth in both directions neutralizes end thrust. Herringbone gearing is generally used in enclosed drives, where fluid lubricants can be employed.





THE HYPOID GEAR

In contrast with the conventional spiral-bevel gear where motion is largely of a rolling nature, the hypoid develops a longitudinal sliding motion between the teeth of the pinion and ring gear. This greater sliding action between the teeth of a set of hypoid gears creates a wiping effect which, combined with high tooth pressure, may rupture the lubricating film unless the lubricant is manufactured to develop high load-carrying capacity.

WORM GEAR SETS

The two members of a worm gear set are known as the worm and the worm wheel, or gear. The worm resembles a screw, although it is really a special form of helical gear, and its teeth are referred to as threads.

The worm is usually made of a hard, wear-resistant steel; the worm wheel, which resembles a helical gear (except that it is throated, or curved on the face to envelope the worm partially), is preferably made of a grade of bronze having good bearing properties. The worm is normally the driver, and its action on the worm gear is quite similar to the action of a screw on a nut. Due to the wedge-like action of the worm thread on the gear tooth, it is relatively easy to obtain quiet operation with this type of gearing; it also provides a very wide range of speed reductions.

TABLE II

Service	Vis. Range (Sec. Saybolt Univ. @ 210° Fahr.)
For high speed, high pressure gears.	50 to 75
For smaller units of medium speed where gears and bearings must be lubricated with the same lubricant	70 to 115
For large units of medium speed where gears and bearings must be lubricated with the same lubricant	130 to 150
For gears of large pinion stands where a separate system, using lighter oil, is used for the bearings	230 to 275
For heavy duty mill pinions and reduction gear sets	400 to 1000

NATURE OF THE LUBRICANT

The ideal gear lubricant must possess certain very definite properties, such as:

1. Sufficient adhesiveness to insure that it will remain on the teeth and resist the action of centrifugal force.
2. Such a viscosity as to form a suitable film, regardless of tooth pressures or temperatures.
3. No tendency to harden or become brittle and chip off in event of exposure to abnormally low temperatures.
4. Sufficient "oiliness" or lubricating ability to reduce to a minimum the friction which occurs between the teeth.
5. Sufficiently low cost to enable it to be purchased and applied at a reasonable expenditure in comparison with the value of the service rendered.

In any gear installation the pressures usually encountered will be high; they may be especially severe on the bearing surfaces, inasmuch as a relatively small area of contact is involved. The pressure developed by this contact is constantly shifting as the teeth are subjected to varying directions of load application. Were rolling contact alone involved, the intensity of such a load momentarily on any part of a gear tooth could be disregarded. But sliding motion is practically always present as well; this explains the abnormal wear that occurs where gears are not properly lubricated, or in other words, where the tooth surfaces are subjected to a continual abrasive action.

There are any number of gear lubricants on the market today which have been designed to meet these requirements. They will vary all the way from fluid mineral oils, to intricate compounds, some of which may contain "fillers". "Fillers" serve but one purpose in a lubricant; to increase the viscosity and weight. They possess no appreciable lubricating value. Therefore, "fillers" should not be used as they are deceiving, and may lead an uninformed user to feel that his lubricant is suitable, when, in reality, it is affording comparatively poor protection against wear. The necessary adhesive characteristics may also be inadequate. As a result, when used under high-speed conditions, or wherever the gears may come into contact with water, acids, alkalis, or chemical fumes, the gear teeth may lose their protective film of lubricant, due either to its being thrown off by centrifugal force, or washed from the wearing surfaces.

For Worm Gears

Except where the speeds are very low and the loading relatively light, worm gears are generally enclosed, and bath lubricated. Open worm gears, where used, must be lubricated according to the speed and size. Normally they require a lubricant that will adhere to the teeth and yet be fairly fluid. Enclosed worm gears, particularly where a hardened steel worm operates with a bronze gear, are usually lubricated with compounded steam cylinder oils, or non-corrosive lead soap lubricants. These rather heavy-bodied oils are necessary in worm gearing, to resist the squeezing-out pressure exerted by the sliding tooth contact and to provide the protective film between the teeth that is depended upon to minimize the friction of the sliding motion inherent in worm gearing. At the same time they cushion the impacts between the teeth

Fig. 7—BURNING

This condition is indicated by discoloration of the tooth surfaces of the type associated with high temperatures. Such discoloration indicates that excessively high temperature has actually occurred, and may be caused by overspeed, overload or faulty lubrication. Burning may result in a reduction in the hardness of hardened steel gear teeth and worm threads, making them unsuited for carrying the specified load.

resulting from gear inaccuracies, or unevenness of the load being transmitted.

In the average bath lubricated worm gear installation, either the worm or the gear is permitted to dip into the lubricant according to the size and arrangement of the gearing, thus providing a sufficient amount of lubricant on the teeth to afford a protective film, but not enough to cause "drag."

CONDITIONS OF OPERATION

Gears may be either encased or exposed, according to the nature of their service and the extent to which they require guarding, or protection against abrasive matter or dust. Exposed gears may often present lubrication difficulties. Normally, they will require a lubricant which will adhere tenaciously to the teeth and resist the action of centrifugal force, speed, and temperature changes.

Where tooth pressures are not abnormal and the teeth are not subjected to heavy shocks, the lubricant viscosity should be chosen accordingly. If the lubricant is too heavy it will defeat certain of the advantages of lubrication by imposing more drag on the gears and increasing their power consumption. As tooth pressures increase, however,

Fig. 8—ROLLING and PEENING

These terms refer to a plastic flow of the tooth surfaces, which may occur when the material in the gears is ductile in compression, and of insufficient hardness. *Scoring* may or may not be present. One effect of rolling is the formation of slight "fins" at the top edges and ends of the teeth. Rolling refers to that condition where plastic flow takes place due to heavy continuous loading: *Peening* where the load is intermittent resulting in a plastic flow of the material due to "hammer blows".

the viscosity of the lubricant should be somewhat higher in order to insure that the film on the teeth will be able to resist the squeezing action of their surfaces, especially when sliding motion takes place. Here we are approaching the condition where a lubricant of increased film strength should be used, i.e., having E.P. properties.

The presence of considerable dust in the air as a result of materials processed, as in the cement or rubber industry, may cause exposed gear lubricants to become veritable grinding compounds, if they are too adhesive to be regularly displaced by fresh lubricant. Here it may be necessary to compromise and use a much lower viscosity oil than would otherwise be desirable.

The heavy pressures that are customary on certain types of steel mill pinions, rubber plant mixers, or cement mill kilns, may squeeze out ordinary lubricants, permitting actual tooth contact, and calling for the use of a mild E.P. lubricant.

The frequence of re-lubrication of exposed gears

Fig. 9—CRACKING and CHECKING

***Cracking* refers to the occurrence of single or scattered cracks in the tooth surface which do not necessarily result in failure.**

***Checking* refers to the formation of numerous and closely grouped cracks in the surface.**

Cracking* may result from loading and lubricating conditions causing excessive temperature fluctuations; and also from excessive hardness. *Checking* may result from several causes. The direction and arrangement of the *cracks* and *checks* usually indicate the probable causes. Frequently, *cracks* and *checks* can only be detected by etching or by the "magnaflux method". For cracks in fatigue failures, see *fatigue breakage.

depends entirely upon the service conditions. They must never run dry, nor, in turn, should they be over-lubricated; otherwise, a sloppy condition will prevail. Experience will dictate the proper viscosity, just as it will the best method of application. A grade suited to clean operation may not maintain an efficient lubricating film under dirty conditions.

Where heavy bearing pressures prevail, these, in turn, may be transmitted to the gear teeth to some extent. Sometimes adjusting screws are employed to regulate the pressure to suit the work; widely varying duty may, therefore, be demanded of some reduction and driving gears. Where slower speeds are customary, the possibility of over-heating or throwing of the lubricant is reduced; yet wear may be appreciable if a proper film does not coat the teeth completely.

Sliding motion is most likely to occur when the teeth first come into contact and as they become disengaged, the points of the respective elements developing a scraping action on the sides of the adjacent teeth. Both wiping action and squeezing may occur at these times. Wiping or scraping off of the lubricant is most apt to occur where the teeth are sliding; squeezing out is possible as maximum pressures are encountered. Wear will occur more rapidly at the points of approach and recess of the teeth due to the sliding friction involved; whereas, the intermediate tooth surfaces adjacent to the pitch line being subjected to rolling action, will resist wear more effectively.

Fig. 10–CHIPPING

This term refers to the breaking off of portions of material at the edges or boundaries of the teeth. It may indicate excessive brittleness, when it occurs under normal load. Another term indicating this condition is *spalling.*

METHODS OF GEAR LUBRICATION

Gear lubricants must be applied according to the design of the installation. We are most generally familiar with automotive practice where the gears in the transmission and differential are bath lubricated. Contrast this with industrial production; viz., the gears which drive the rolls on certain rubber machines which may be either bath or hand lubricated; the gearing on excavating machinery which is largely hand-oiled; and turbine reduction gears which are lubricated by force-feed. This latter method of lubrication is also now widely applied to enclosed type steel mill reduction gear sets.

So a wide variety of conditions exist, each of which may require special consideration according to the design of the machine, the size and number of the gears and the products being handled. Certain of the latter will be of a perishable nature such as foodstuffs, paper and textiles. Gearing on the attendant machinery must be so lubricated that there will be practically no chance of the gear lubricant splashing, dripping or being thrown onto these products.

Analysis of industrial machinery presents five distinct conditions pertinent to gear lubrication:

1. Where the gears are enclosed in a suitable casing, out of contact with the bearing lubricant, running either in a bath of oil or being lubricated by force-feed.
2. Where gears run in an enclosed case, the gear lubricant at the same time serving the bearings, as is true in the majority of industrial gear drives.
3. Where gears are entirely exposed, the lubricant being applied by hand.
4. Where the gears run exposed, but with their lower portions encased so that bath lubrication is possible.
5. Where gears are open, and exposed to such dirty conditions as to render practically any lubrication ineffectual.

Where and when to use any specific grade of lubricant is, therefore, oftentimes quite a problem. It is disconcerting to attempt to heed all the modern arguments in favor of industrial plant efficiency, and at the same time have a set of gears which may refuse to function properly with ordinary methods

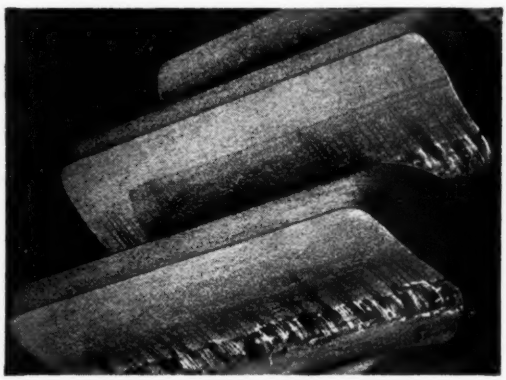


Fig. 11–GOUGING

This may occur in unhardened gears when there is interference between the flank of the driving pinion and the tip of the driven gear. The top edges of the gear teeth may *gouge* the material near the roots of the pinion teeth. A similar effect may occur between the edge of a hardened worm thread and the teeth of a worm gear.

of lubrication. Such conditions are not entirely hopeless, even though perhaps the air may be filled with dust, or the gears subjected to hot water or acids, etc. The petroleum industry has solved this problem by developing specialty lubricants refined so as to stick and lubricate even when totally submerged in practically boiling water.

There are available similar lubricants for pressure conditions as already mentioned. These along with the wide range of straight mineral gear lubri-

cants will serve virtually any condition of operation or means of application. It only requires judicious study of these conditions along with the physical characteristics of the lubricants and the application of the gearing.

Clean Conditions Promote Good Lubrication

This brings us to means of application—likewise the importance of cleanliness. Where pans are furnished for bath lubrication they should be cleaned out at regular intervals, since any dust that may have gained entry may destroy the adhesiveness of the gear lubricant, tending to form a pasty mass which the gears cannot pick up.

Where the gears dip in a bath of lubricant, this bath should be just deep enough so that the lowest teeth are just covered. This will give ample lubrication and keep the consumption at a minimum.

When the lubricant is applied by hand, it should be heated if necessary to reduce it to the consistency desired, and painted on with a brush, or poured on from a dipper as the gears are slowly revolved towards each other. Applying it in a fine stream or by spraying is most economical and effective.

Fig. 12—OVERLOAD and BREAKAGE

This term refers to gear tooth breakage caused directly by an unexpected shock or overload — due for instance to the jamming of other machinery — of a nature which cannot be attributed to improper design or faulty manufacture.

Gear lubricants should be applied to open gearing relatively frequently and in small quantities, rather than in considerable volume and at longer intervals. Thus there will be less wastage and less danger of gobs of lubricant being thrown off by centrifugal force to contaminate the products passing through the machine. In case the lubricant becomes laden with foreign material and packs at the roots of the teeth or between the gear and its shield, this cake often can be softened and removed by the use of kerosine or some petroleum solvent.

NOISY OPERATION

As a pair of gear teeth must operate freely on their centers with adequate clearance to allow for normal expansion with increase in temperature, lubrication becomes a prominent factor in so filling this clearance as to cushion the impact effect between the teeth. The lubricant may also become a contributing factor to the ultimate noise effect, if excessive impact or splashing within itself should develop. This can be caused by too rapid circulation of a relatively fluid gear lubricant, or carrying

Fig. 13—FATIGUE and BREAKAGE

This term refers to tooth breakage as a result of repeated loading, and is usually characterized by the formation of *cracks* at highly stressed locations, which progressively extend in area and depth until failure occurs. *Fatigue breakage* is not necessarily an indication of poor design or faulty manufacture. It merely means breakage after a large number of repetitions of load, as distinguished from overload breakage, which may be the result of a single application, or a comparatively few applications of excessive load. In fact, it is the practice in automotive and aircraft design to proportion the gears, so that they will fail by *fatigue* after they have fulfilled their rated length of service. It is usually possible to ascertain from the character of the surfaces of the fracture, if the failure is from fatigue.

the bath level of a heavier product so low that the gear teeth will "slap" into it instead of churning.

Lubrication should not be regarded too literally as an eliminant for gear noise; it will often reduce the effect which may develop through improper design, installation, or operation, but it cannot eliminate the cause. Granting, however, that the latter oftentimes cannot be corrected, effective lubrication will be very helpful in preventing scoring or galling which may develop through continuous and excessive tooth loading. Ultimately, these defects may be observed, however, even with the best of lubrication; when and if this may occur, it is no fault of the lubricant, unless application of the latter has been neglected. Excessive noise can be a warning that misalignment has developed and should be investigated.

TABLE III
WHEN THERE IS TROUBLE

The Condition	Most Prevalent On	The Cause	To Correct It
Abrasive wear or scoring	Spur, Helical and Bevel Gears	Misalignment or rough surfaces; improper tooth contact; sliding under heavy load; too low oil viscosity; low starting temperatures.	Increase oil viscosity; use oil with mild non-corrosive E.P. additive; use means for preheating to raise the starting temperature.
Galling	Spiral, Bevel and Hypoid Gears	Oil film rupture, high surface temperatures.	Use oil with mild non-corrosive E.P. additive; use means for cooling to reduce temperatures.
Pitting	Any or all types of gears	Occurs with rolling as well as with combined rolling and sliding with oil too low in viscosity. More prevalent on rough surface finishes or where local tooth overload prevails.	Use an E.P. oil; increase the oil viscosity; try to get gears of better surface finish; increase the surface hardness or metal toughness. Improve tooth alignment and load uniformity by shimming under bearings or adding outboard bearings to over-hung pinions.
Burning	Any or all types of gears	Overload, or lack of lubrication.	Run under conditions for which gear was designed. Lubricate.

CONCLUSION

Research in gear lubrication has indicated that sufficient pressure can be developed in a fluid lubricating oil film to carry the loads developed and transmitted by the teeth, if they are designed on a sound basis, for example, in line with A.G.M.A. practice. Maximum pressure or load will depend upon the design condition, the load, the speed, and viscosity of the oil. Design is fixed for any given installation. The others in turn are more or less contingent upon each other, although the load and speed also may be fixed. The viscosity is most easily changed in practical service—it can be varied up or down according to the load and speed. Heavy loading and lower speeds call for a heavier oil. The operators rule is to reduce the oil viscosity with increase in speed; increase it with increase in load and consider the nature of the lubricant from an E. P. point of view.

CAUTIONS – GEAR LUBRICATION

Check alignment of driving and driven shaft connections.

Inspect after first half hour after starting. Evidence of improper selection of lubricant often shows up during this period; or evidence of misalignment may be indicated.

Watch the oil level. The amount of oil in an enclosed gear unit is just as critical oftentimes as the kind of oil.

Check oil level when machine is standing still; otherwise if checked while running, a false level may be indicated.

Figures 1 through 13 with terms and definitions used in designating gear tooth wear and failure are reproduced by courtesy of American Gear Manufacturers Association from A. G. M. A. Tentative Standard Nomenclature.

Printed in U.S.A. by
Salley & Collins, Inc.
305 East 45th St.
New York 17, N. Y.

SCHEDULE OF TEXACO LUBRICANTS FOR INDUSTRIAL GEARS (CONTINUED)

TYPE OF GEAR	DESCRIPTION	AMBIENT TEMPERATURES	NORMAL OPERATION	HEAVY DUTY, WHERE EXTREME PRESSURE LUBRICATION REQUIRED	IN PRESENCE OF WATER OR CHEMICALS
WORM	Gears enclosed, casings oil tight, bearings separately lubricated.	Below 40° F.	Thuban 80	Meropa Lubricant–1	
		40° to 100° F.	Cavis Cylinder Oil 650T Cylinder Oil Thuban 90	Meropa Lubricant–3	
		Above 100° F.	Cavis Cylinder Oil Thuban 90 or 140	Meropa Lubricant–3 or 6	
	Gears enclosed, casings oil tight, gear lubricant to serve bearings as well.	Below 40° F.	Thuban 80 or 90	Meropa Lubricant–1 or 3	
		40° to 100° F.	Cavis Cylinder Oil 650T Cylinder Oil Thuban 90	Meropa Lubricant–3	
		Above 100° F.	Cavis Cylinder Oil Thuban 90 or 140	Meropa Lubricant–3 or 6	
	Gears entirely exposed, hand lubricated.	Below 40° F.	Thuban 90 or 140	Meropa Lubricant–3 or 6	
		40° to 100° F.	Thuban 140	Meropa Lubricant–6	Crater No. 1x
		Above 100° F.	Thuban 140	Meropa Lubricant–6	Crater No. 1x
	Gears exposed, bath lubricated.	Below 40° F.	Thuban 90	Meropa Lubricant–3	
		40° to 100° F.	Thuban 140	Meropa Lubricant–6	Crater A
		Above 100° F.	Thuban 140 or 250	Meropa Lubricant–6 or 7	Crater A
RACK AND PINION	Teeth entirely exposed, hand lubricated.	Below 40° F.	Crater Nos. 00 or 0	Meropa Lubricant–6	Crater A or No. 1x
		40° to 100° F.	Crater Nos. 1 or 2	Meropa Lubricant–7 or 8	Crater Nos. 1x or 2x
		Above 100° F.	Crater No. 3	Meropa Lubricant–8 or 10	Crater Nos. 2x or 5x
	Teeth exposed, bath lubricated.	Below 40° F.	Thuban 90 Crater No. 00	Meropa Lubricant–3	Crater A
		40° to 100° F.	Thuban 140 Crater Nos. 00 or 0	Meropa Lubricant–6	Crater A or No. 1x
		Above 100° F.	Thuban 140 or 250 Crater No. 0	Meropa Lubricant–6 or 7	Crater A or No. 1x

NOTES The above recommendations are naturally more or less general based on average pressures and for small to medium sized gears.

1. *In case of light loads or high speeds:* Use next lighter grade of gear lubricant.
2. *If gears are very large:* Use somewhat heavier grade than that recommended above.
3. *Meropa Lubricants* are highly resistant to water and should be recommended where both a water resistant and an EP lubricant is desired.
4. *For Turbine Reduction Gears:* Use Texaco Regal Oils (R&O).
5. *For cast gears:* Use the next heavier grade of gear lubricant recommended.
6. *Texaco Craters* under certain conditions are recommended for enclosed gears and exposed worm gears.
7. Should ambient temperatures be extremely low or high, or should any uncertainty exist as to the correct lubricant recommendation for a specific application, consult your local Texaco Lubrication Engineer.